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Weldability and Post Weld Heat Treatment of T23 Boiler Grade Steel

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***Abstract*—*T23 is a low alloy ferritic steel used for boiler super heater and re-heater tubes and water panels in complex fuelled power plants as they exhibit superior high temperature strength and creep behaviour compared to other low alloy ferritic steels. T23 steel is in bainitic structure which holds greater toughness than tempered martensite and also they possess increased resistance to thermal fatigue. With the help of T23 steel, the weight and piping component of the boiler can be reduced. The microstructure of the weldment without proper Post Weld Heat Treatment (PWHT) was not in equilibrium state which led to the secondary hardening during subsequent exposure at high temperature. So there occurred a significant increase in hardness due to non-tempered weld joints and decrease in toughness. Therefore, Post Weld Heat Treatment for T23 steel is necessary. Using Tungsten Inert Gas (TIG) process, the T23 steel was welded under suitable welding parameters (welding current, voltage and shielding gases). A study was done to know the effect of Post Weld Heat Treatment on T23 steel and also the influence of welding parameters. Hardness of T23 steel was measured. The heat treated specimen is examined through Optical microscope and Scanning Electron Microscope. Finally it was noticed that the Post Weld Heat Treatment has enhanced the mechanical properties as well as the metallurgical arrangement of the T23 steel.*
Keywords*— *T23steel, TIG process, Alloying elements, Post weld Heat Treatment, SEM analysis.

I. INTRODUCTION

The aim of increasing the power plant efficiency through raising the steam pressure and temperature and also to provide energy at lowest possible cost seems to be a challenge for the material and plant layout. Thus, the increase in steam parameters acquires the new requirements to the ferritic steel used in the boiler.

The most recent requirement in power plant is increased creep rupture strength, which led to the introduction of low-alloy Cr steel in bainitic phase. The low chromium steel grade T23 is the fine material for the components of ultra-supercritical power plant and also acts as the potential replacement material for ASTM T22 which was in older stages for the power plant.

The T23 steel was derived from T22 steel by the suitable addition of alloying elements like Tungsten(W), Vanadium(V), Niobium(Nb) and limiting the Carbon(C) and Molybdenum(Mo) content. This enables the steel to enhance the creep resistance and easier weldability. So, it is suited for water wall panels in ultra-super critical boilers. They are also used for super heater, reheaters of conventional power plant boilers. The material is capable of being used and exhibits properties of creep resistance and toughness without PWHT in case of thin walled tubes.

This paper sets out to know the effect of PWHT for T23 boiler grade steel. In order to investigate the effects, the microstructure using Optical Microscope and the SEM images are plotted. The behaviour of the material at various temperatures is processed for better understanding the nature and responses of the material at the particular temperature.

1.1 COMPOSITION AND PROPERTIES OF NEW STEEL GRADES

To enhance the creep-rupture strength, the elements V, Nb and N were added to from stable particles. Also, W was added and simultaneously the Mo content was reduced, to form T23 grade steel. The slow cooling rate of T23 results in tempered bainitic and martensite structure. Due to low carbon content the hardness value is limited to about $350HV_{10}$. The addition of boron retards the transformation into ferrite. Due to low carbon content it provides a good weldability. It avoids PWHT for thin products. Addition of V, Nb combined with C and N forms carbides, nitrides and carbo-nitrides of MX type and cause a fine precipitation in the matrix, increasing the strength of the new grade material. Further addition of tungsten improved the creep resistance. According to ASTM standard A213 standard specification for seamless ferritic and austenitic alloy steel boiler, super heater and heat-exchanges tubes:

Table: 1.1

Composition	Weight Percentage
Carbon	0.04-0.10
Manganese	0.10-0.60
Phosphorous (max)	0.030
Sulphur (max)	0.010
Chromium	1.90-2.60

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Molybdenum	0.05-0.30
Vanadium	0.20-0.30
Tungsten	1.45-1.75
Columbium	0.02-0.08
Boron	0.0005-0.006
Nitrogen	0.030
Aluminium (max)	0.030

The ferritic alloy steel can be reheated for heat treatment. Heat treatment shall be carried out separately and in addition to heating for hot forming.

1.2 EFFECTS OF ALLOYING ELEMENTS

a) Chromium:

It enables the better corrosion resistant property. It increases the scaling resistance and also increases tensile strength of the material.

b) Manganese:

It improves hot working properties. Up to 2% there is no effect on strength, ductility and toughness and above 2% there is increased yield and tensile strength. It also stabilizes austenitic structure.

c) Molybdenum:

It increases the creep resistance of the material when subjected to higher temperature.

d) Silicon:

It increases scaling resistance. e) Sulphur and Phosphorous:

It increases the machinability and it increases the ductility of the material.

f) Titanium and Columbium:

It prevents intergranular corrosion by stabilizing the carbon and also it produces the fine grain size.

1.3 OXIDATION BEHAVIOR OF T23 STEEL

Internal steam oxidation is the cause of various problems in power plants, such as the formation of oxide layers reducing the tube thickness and increasing the stress and increase in metal temperature during operating

II. WELDING PARAMETERS FOR T23 BOILER GRADE STEEL

The welding employed is Gas Tungsten Arc Welding Process (GTAW) which is done manually. Groove weld with butt joint angle of 167° and root spacing of 2mm is maintained uniformly throughout the process. 2CrWV type solid filler metal is used in this process. Table 2 illustrates the composition of filler metal. The diameter of the filler metal is 2.4mm.Table 3 shows the electrical characteristics and Table 4 shows the composition percentage of shielding gas. The GTAW filler metal allows the welding of thin wall tubes without PWHT. Here the thickness of the material is above 10mm and also the investigation of hardness values in the weld metal is below the hardness number as per ASTM E384 for the material so PWHT of 720°C-760°C is carried out.

Table.2.1

Sample Ref No.	*Impact Energy (J)*	*Sample Ref No.*	*Impact Energy (J)*
J1	36, 39, 39	J4	31, 30, 27
J2	28, 28, 20	J5	19, 18, 14
J3	37, 35, 36	J6	14, 14, 16
Req.	**14J (Average)**	**Req.**	**14J (Average)**

III. TESTING

The low alloy bainitic steel T23 is welded with the above welding parameters. The test begun by calculating the tensile strength of the parent metal followed by hardness test, carried out by Vicker's Hardness Scale. The samples were prepared for examination by means of both Optical microscope and Scanning Electron Microscope (SEM) studies were carried out on the effect of PWHT in the specimen.

3.1 EXPERIMENTAL RESULTS

3.1.1 HARDNESS MEASURMENT.

Test Method – ASTM E384

Table.3.1

	Hardness – HV_{10}				
	PM	***HAZ***	***Weld***	***HAZ***	***PM***
J1	147/149	156/160	167/170	156/158	147/151
J2	176/176	228/232	224/224	228/232	176/176
J3	148/148	147/147	183/181	165/167	148/148
J4	183/181	240/240	228/232	232/230	183/181
J5	183/181	279/274	268/268	279/285	183/181
J6	181/183	274/279	274/274	274/274	181/183

3.2 CHARPY IMPACT TEST:

Test Method - ASTM A370

Longitudinal impact samples of size 2.5 x 10.0 x 55.0 mm, three each from weld region were taken, tested at +20°C for checking the toughness of material and the values are as below.

3.3 MICROSTRUCTURE

The samples were polished with simple hand belt grinding placed with abrasive paper (240,300,400 and 600 grit) on

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the top. The specimen is etched with 5% Nital at a time of 30 seconds. Micro examination of the weld joints show a microstructure of bainite in weld, HAZ and parent metal of all samples. Refer Photos 1 to 18.

POST WELD HEAT TREATMENT IN ALL ZONES

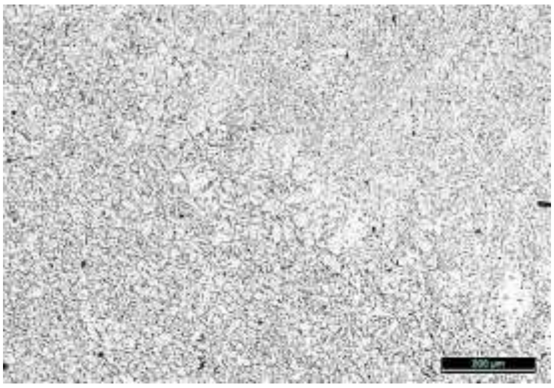

Fig.1:HAZ+Weld 100X

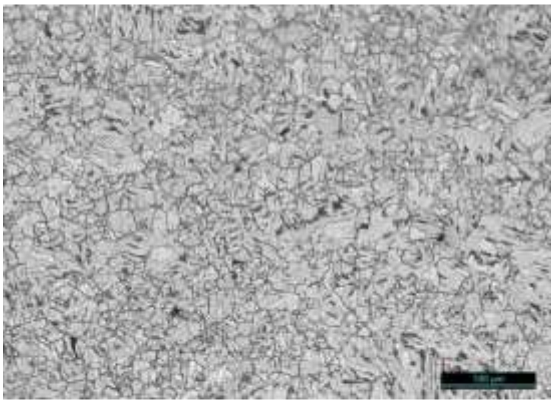

Fig.2:Parent Metal 100X

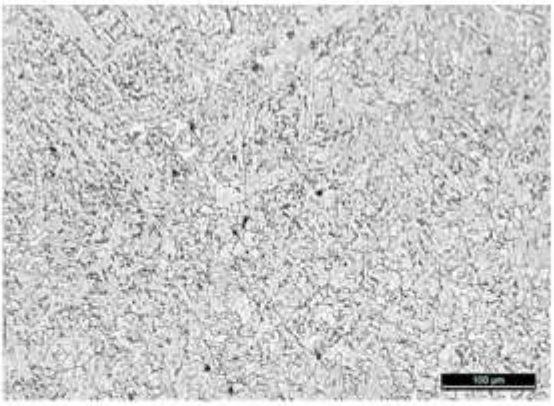

Fig 3:Weld 100X

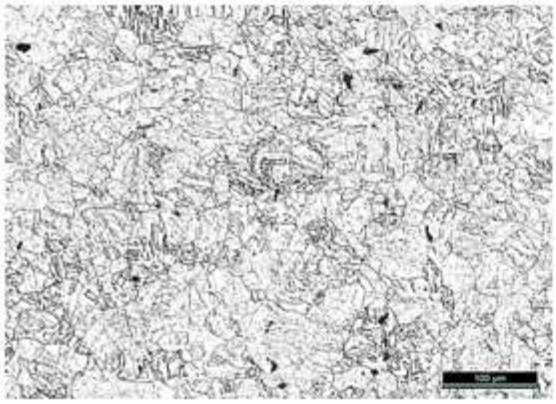

Fig 4:Parent Metal 100X

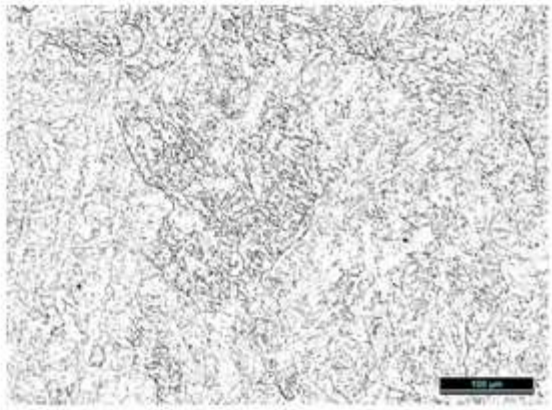

Fig 5:Weld 100X

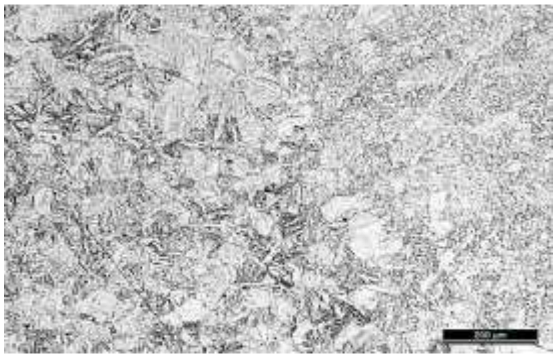

Fig. 6:HAZ+Weld 100X

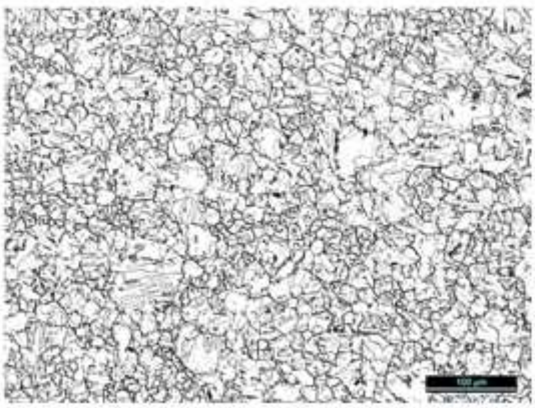

Fig 7:HAZ+Weld 100X

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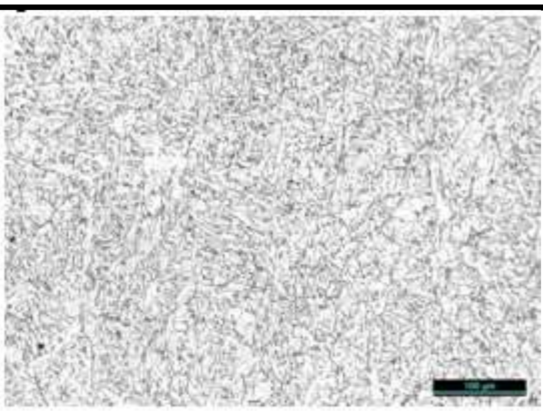

Fig 8:Parent Metal 100X

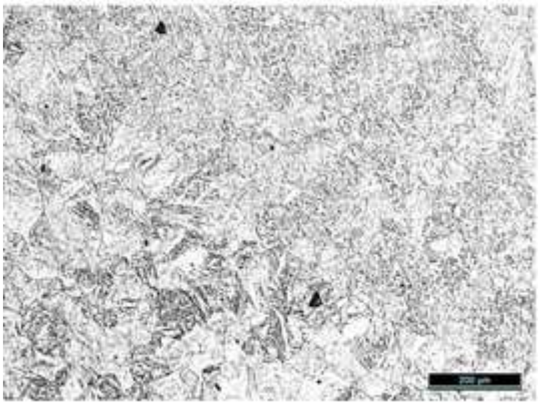

Fig.9:Weld 100X

3.4 SEM ANALYSIS

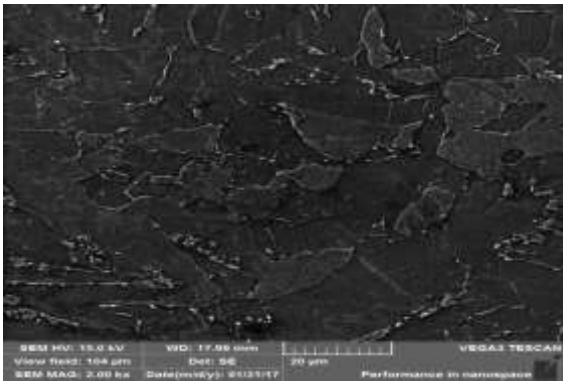

Fig.10: WELD METAL ZONE AT 1500X

From SEM analysis it was found that the material is free from defect and inclusion. It is also seen that, after PWHT the bainite has uniformly distributed which increases the mechanical and metallurgical features of the T23 material.

IV. OBSERVATION

From the hardness test of T23 sample is increased by the effect of Post Weld Heat Treatment (PWHT) and the energy absorption rate of the sample is increased enormously. In Microscopic image the grain arrangement after PWHT seems to be fine grain structure. In the Scanning Electron Microscope it seems that the sample is free from defect and inclusion and also the effect of PWHT increased the material properties.

V. CONCLUSION

From the results of tensile test, hardness test, impact test, microstructure and SEM analysis the actual state and the effect of Post Weld Heat Treatment is sorted out. Post Weld Heat Treatment for the material thickness greater than 13mm is necessary to enhance the properties of the T23 steel used in water panels of Boiler. Post Weld Heat Treatment of ferritic steel improves resistance to brittle fracture also it improves the toughness and relieves the residual stresses developed in it.

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